An Innovative Mechatronics Course for a Traditional Mechanical Engineering Curriculum

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Abstract

Many Mechanical Engineering Departments have recently or are now developing programs and/or courses in mechatronics. The emphasis of these programs/courses varies from institution to institution. The programs at four Canadian universities are described briefly and a new elective course in mechatronics at Queen's University is described in detail. The primary objective of the course is to create a sense of opportunity and excitement about mechatronics system design. This course focuses on the practical implementation of simple mechatronic systems with particular emphasis on the electronics for conditioning and interfacing of sensor signals and driver control signals. The laboratory portion of the course is based on the Basic Stamp II, a user friendly microcontroller from Parallax Inc. By the end of the course, students understand a relatively simple system of sensors and actuators under the supervision of a microprocessor engaged in on/off or simple PID control.

1. Introduction

Mechatronics is a word which means different things to different people. Mechatronics can be a philosophy of design which brings together many disciplines in concurrent engineering environment. Mechatronics can be the extension of this philosophy into complete system modeling and simulation. Mechatronics can simply refer to systems with sensors, actuators and embedded microprocessor control. It has also been said that mechatronics is, "simply good design practice" [1], or that it is really all about, "getting ME's and EE's to work in harmony"[2].

When it comes to designing a mechatronics curriculum or course, it is not at all clear where the emphasis should lie. It can be argued that a student of mechatronics engineering "should complete two undergraduate degrees, one in mechanical and the other in electrical engineering [followed by] graduate-level work in systems design and control theory"[3]. On the other hand, one might argue that very few people have the ability to assimilate and integrate the breadth of knowledge required to become a "mechatronics engineer". If this premise is accepted, then mechatronics education should be about technical specialization with teamwork skills.

Over the past decade, many mechatronics courses and programs have come into existence. As far as we can determine, every one of these initiatives has originated in a mechanical engineering department. This is particularly significant in light of the fact that engineering curricula, in

North America at least, have been under increasing pressure to include more material in less time. Clearly, mechatronics, whatever it means, is a high priority.

2. An Overview of Some (Canadian) Mechatronic Courses

To illustrate the approaches to the handling of mechatronics taken by Canadian schools, an overview will now be given of selected mechatronic courses and streams. For up to date information on mechatronics at some of the American Schools (for example Ohio State, Rensselaer, Stanford, University of California, and Washington), one is referred to the recent symposium on Mechatronics in Mechanical Engineering Education held at the 1998 ASME Congress [4]. One must remember that schools outside of North America tended to deal with the subject of mechatronics at least a decade earlier than those in North America. A useful link to mechatronics at the international level is given at *http://www.mechatronik..uni-linz.ac.at/international/index.en.html*. This site is maintained by the University of Linz in Austria and is entitled “Mechatronics Around the World”.

The Department of Mechanical Engineering at the University of British Columbia has in place a five year combined B.Sc. and M.Eng. degree entitled “Electro-mechanical Design Engineering”. The students take all core undergraduate mechanical engineering courses, plus selected digital electronics and software engineering courses. The culmination of the program is two twelve month project courses that involve advanced machine design (MECH 551) and electronic systems design (MECH 522). The calendar description for the latter reads as follows:

> MECH 552 Electro-mechanical Design Project: One year long electronic design project targeted to the automation industry. Students will have to design a single board computer and real time software dedicated to control or monitoring of a machine or process. A prototype board will be designed with PCB CAD software, manufactured and tested on the targeted machine or process. Projects from industry are welcome.

The word “mechatronics” is not actually mentioned anywhere in the brochure for the UBC program. Although the philosophy of the program is clearly one that identifies with mechatronics.

In 1996, the Mechanical and Manufacturing Engineering Department at the University of Calgary introduced a new required course on the subject of mechatronics. The calendar description for the course ENME 461 reads:

> ENME 461 Mechatronics: An introduction to electromechanical components and systems including: electromagnetic devices; mechanical and fluidic devices; modelling of physical systems; system linearization; introduction to feedback; analogue and digital control, fuzzy logic and expert system control.

The basic outline for the course includes the following topics: modeling of dynamic systems, differential equations review, simulation methods, control theoretic concepts, microprocessors and computers, fuzzy logic and expert systems and mechatronic systems design. Examples are predominantly simulation based using PC-MATLAB. The course is part of a sequence of three courses in electro-mechanical systems: ENGG 325 (Circuits and Systems), ENME 461 (Mechatronics) and ENME 585 (Control Systems). This course places a strong emphasis on the design process and teamwork.

In 1995, the Mechanical Engineering Department at McMaster University introduced an elective course on the subject of mechatronics. The calendar description for MECH 4H03 reads:

> MECH ENG 4H03 Mechatronics: Integration of mechanical engineering with electronics and computer control. Sensors, actuators (including pneumatic and hydraulic), modelling using building block and state space methods, model-based control, programming of PLCs with practical demonstrations.

The course emphasizes both classroom theory and hands-on experience with the following laboratories:

- PLC programming lab (workcell control with an OMRON PLC)
- heat control lab (on-off and PI control with an Intel 80196 microcontroller)
- pneumatic actuator lab (PID control with an Intel 80196 microcontroller
- stepper motor lab (linear ball screw actuator driven by a stepper motor)

The basic outline of the course includes coverage of: sensors, actuators, PLC’s, dynamic system modelling, computer simulation, control theory and computer interfacing.

In 1997, an elective course in Mechatronic Systems Design was introduced in order to meet a growing demand at the undergraduate level as well as to address the evolving needs of the profession.

> MECH 452 Mechatronics Systems Design: Mechatronics is a term which describes the integration of mechanical and electrical engineering and represents a new approach to the development of modern products. In this course, students will develop a basic understanding of the non-mechanical aspects of a mechatronic system. Simple mechatronic systems will be developed in laboratory sessions. Working in groups, students will design and implement a mechatronic system based on the microcontroller used in the laboratory session.

Ultimately, this course will be part of a multidisciplinary grouping of elective courses for students wishing to specialize in mechatronics. A detailed rationale and description of MECH 452 is given in the next section.

It is worthwhile, at this point, to summarize the four different approaches to the subject of Mechatronics in the Canadian context: 1) present a degree program in electro-mechanical design (UBC), or 2) present an elective stream of multidisciplinary courses (Queen's), or 3) present a core stream of multidisciplinary courses (Calgary) or finally, 4) present a single elective course (McMaster). All four approaches have their advantages and disadvantages. The variety of approaches is a reflection of the numerous interpretations of what constitutes mechatronics. Predictably, the common element is at least one course with the title "mechatronics".

3. The Mechatronics Elective at Queen's University

3.1 Student Preparation

The undergraduate curriculum in Mechanical Engineering at Queen's University is relatively conventional. The core is common through the third year and the majority of these core courses fall into traditional mechanical engineering disciplines: solid mechanics, fluid mechanics, heat transfer, mechanical design. In the fourth year, students may specialize through their selection of seven elective courses. There are no predefined streams or options. Within the core, four courses are related to the non-mechanical aspects of mechatronics: Elec 210 – Introductory Electric Circuits and Machines, Mech 215 - Instrumentation and Measurement, Phys 333 – Electronics for Scientists and Engineers, Mech 350 –Automatic Controls. Students entering the fourth year, in general, have not retained much of the material from these four courses. They are, therefore, poorly equipped to apply, let alone integrate, this material in the practice of mechatronic systems design. As a starting point for Mech 452, therefore, only the most basic background in electrical circuits and no background in microprocessors are assumed.

3.2 The mechatronic system – What are the most difficult issues?

For the purposes of the course, a simple model of a mechatronic system is adopted, as shown in Figure 1. Sensors monitor the state of the "real world" or environment. Signals from the sensors are conditioned prior to A/D conversion and subsequent input to the microcontroller. The control system, which is encoded in software, makes decisions based on sensor data and the microcontroller then issues the appropriate digital output signals. As required, these signals then undergo D/A conversion and and/or further conditioning in actuator driver circuits from which direct control signals are issued to actuators.

Of the various aspects of this model, which present the greatest sense of mystery for the typical mechanical engineering undergraduate? Actuators and sensors are, in general, not a significant problem. Although the means of actuation of the actuator may be electrical, the result is usually mechanical. Similarly, there are many sensors whose output signal can be related directly to a mechanical interaction. In our experience, the operation of most sensors or actuators is readily grasped by mechanical engineering undergraduates.

Microcontroller architecture, programming and control system implementation are also potential minefields of confusion. However, if limited to relatively simple cases in which the microcontroller is treated as a "black box", then students readily grasp the basics of on/off control system implementation. The digital character of the microcontroller and the structured nature of its operation give students a comfort level not found in analogue applications. The rules of the game may be a bit complicated but at least they are black and white.

Typically, it is the sub-systems that lie between the microcontroller and the sensors and actuators that cause the most confusion among students. Sensor output signals and actuator control signals come in a bewildering array of guises: low or high impedance, digital or analogue, 0 to10V, -5V to +5V, 0V to 50mV, 5mA to 20mA, DC, AC, pulse width modulated, amplitude modulated, etc… This situation is compounded by the many ways in which these various signals can be transmitted, amplified, filtered, converted or demodulated. The problem gets even worse if we delve into the details of the circuits that affect these miraculous changes on signals. These circuits are assembled from a collection of mysterious devices including: transistors, diodes, op amps, capacitors and inductors.

A fourth year student entering Mech 452 is, typically, able to specify a sensor or an actuator based on the range of the physical parameter to be measured or the physical effect to be achieved. Similarly, with a brief introduction, most students are quickly able to control basic digital I/O functions on a microcontroller. However, few students are able to understand let alone specify, design or discuss with clarity, the sub-systems which lie between the sensors/actuators and the microcontroller.

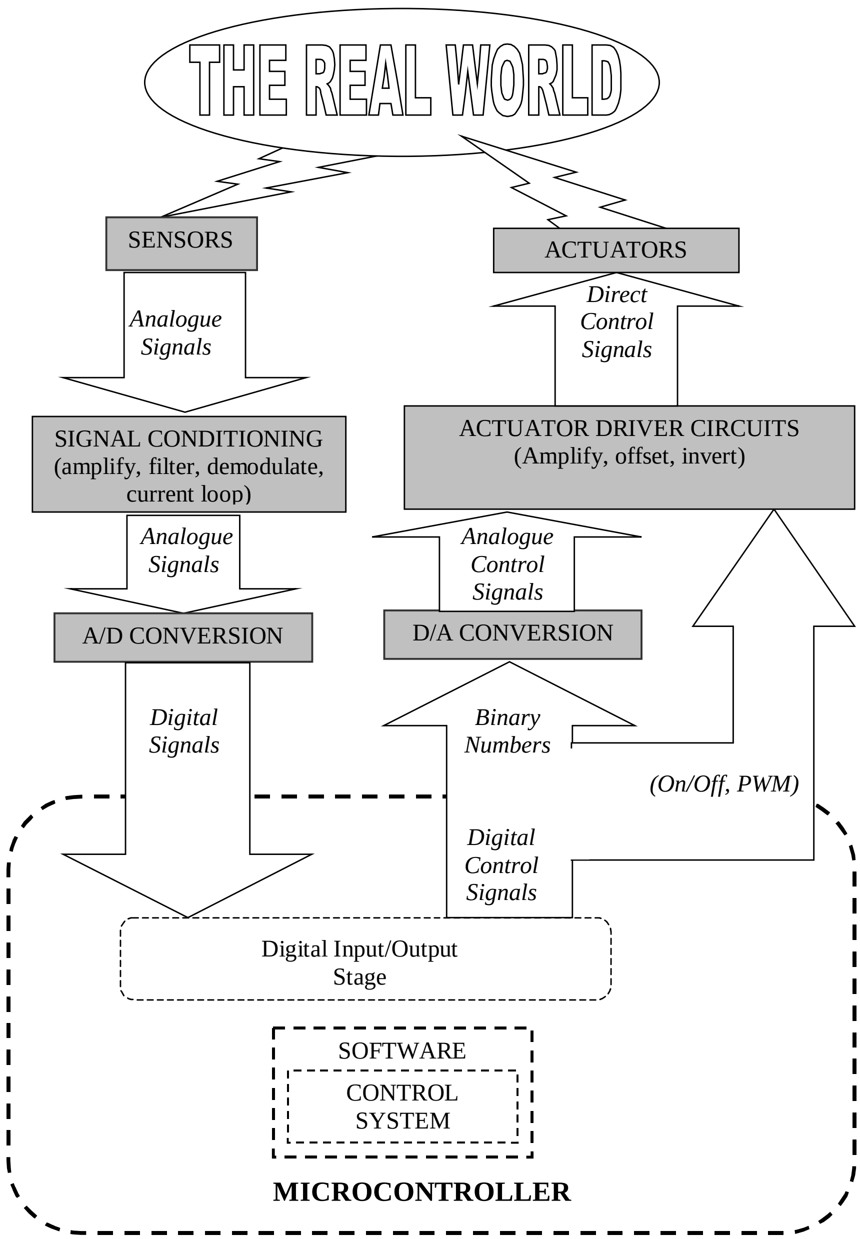

Figure 1 – A schematic view of a mechatronic system

3.3 Course objectives

Given the level of student preparation and the limited time available in a single term elective course, the objectives of this course are relatively modest.

1. To create a sense of opportunity and excitement about mechatronics system design.
2. To demystify and, thereby, to eliminate/reduce fear of electronics and microprocessors.
3. To develop a basic vocabulary and basic understanding of non-mechanical aspects of a mechatronic systems

Note that the objective of the course is NOT to create mechatronics engineers, but rather to foster an attitude and to provide a basic level of knowledge that will encourage students to continue their education and/or to pursue careers in this field. In addition, this course attempts to create an appreciation of basic non-mechanical design trade-offs, so that students will be able to function effectively as mechanical engineering members of a mechatronics design team.

3.4 Course description

For students to appreciate and become excited about the design of mechatronic systems, they must be able to design complete systems, even if these systems are relatively simple. Mech 452 is, therefore, structured to quickly bring the students to a level where they are designing very simple systems and then to increase the complexity of these systems as the course proceeds. In addition, the lecture material in Mech 452 is structured to emphasize signal processing and device interfacing which, as described in the preceding section, is the area of greatest weakness among incoming students. The outline of course material is presented on the following page.

The Basic Stamp II from Parallax Inc. (www.parallaxinc.com) is the microcontroller which is used throughout this course for student activities. It is relatively inexpensive, easy to program and there is a wealth of third party documentation [5,6]. Code is developed in Basic on a user-friendly PC-based environment. The code is then downloaded using a serial connection. For the purposes of this course, we have built development boards that allow: power supply connection to a 9VAC wall adapter, short circuit protected I/O connections and circuit prototyping space. Similar boards are available commercially from Parallax.

The course has three lectures and one tutorial per week as well as a laboratory session every second week. There is no prescribed text as none of those which are currently available [3,7,8,9,10] is compatible with the course objectives. Detailed course notes have been developed and are made available to the students at the start of term. Design-type problems are assigned each week and are discussed in the tutorial session. Student groups undertake design projects in which they must design and assemble a simple mechatronic system based around the Basic Stamp II. These designs are presented in a common session at the end of term.

Wk 1	*1. What is Mechatronics?* *2. Resistive circuits* (ohm's law, parallel and series circuits, voltage divider, potentiometers, input/output impedance, loading errors, power dissipation) *3. Measurement techniques* (DMM's, oscilloscopes, function generators)	
Wk 2	*4. Digital circuits and devices* (basic gates, PLD's, microcontrollers, I/O considerations, application development) *5. The lab microcontroller* (simple programming of the Basic Stamp II)	*Lab 1:* Series and parallel resistive circuits, loading errors, AC and DC measurements using of DMM's, scopes.
Wk 3	*6. Diodes* (p-n diodes, zeners, input protection, LED's) *7. Bipolar transistors* (pnp/npn characteristics, actuator driver circuits, phototransistors)	
Wk 4	*8. D/A and A/D conversion* (resolution, quantization, bias, designs and specifications)	*Lab 2:* Introduction to the Basic Stamp, I/O, simple programming, control of LED's and stepper motors
Wk 5	*9. Electromagnetic devices* (inductors and AC excitation, solenoids, relays, stepper motors, LVDT's, proximity sensors, transformers) *10. Capacitive devices* (capacitors and AC excitation, time constants, passive filters, capacitive sensors)	
Wk 6	*11. Operational amplifiers* (comparator, inverting, non-inverting, differential, summing, integrating, buffering, hysteresis comparator)	*Lab 3:* D/A converter, R/C time constants, bipolar driver circuits and PWM control of a DC motor.
Wk 7	*12. Signal conditioning* (filters, instrumentation amps, isolation amps, voltage/frequency conversion, opto-isolation)	
Wk 8	*13. More actuator control devices* (MOSFET's, JFET's, SCR's, TRIAC's, SSR's)	*Lab 4:* Op-amp based analogue signal acquisition and conditioning.
Wk 9	*14. Power supplies and power conversion* (rectifiers, DC-AC, AC-DC, frequency controllers)	
Wk 10	*15. Microprocessors and microcontrollers* (architecture, I/O, languages, selection criteria)	*Lab 5:* Closed loop DC motor control using op-amps, A/D converter, tachogenerator and encoder.
Wk 11	*16. Overview of actuators and sensors*	
Wk 12	*17. Case Studies*	*Lab 6:* PID control with the Basic Stamp

Week by week, the students become familiar with the hardware and, to a limited degree, the software of a simple mechatronic system. By the end of the course, they are able to understand a relatively simple system of sensors and actuators under the supervision of a microprocessor engaged on/off or simple PID control. Relative to mechatronics courses at other institutions, the distinguishing characteristic of this course is the lack of emphasis on modeling, simulation and control of dynamic systems. Graduates of the Queen's course may not be familiar with these methods, but they have a solid foundation upon which to develop that knowledge.

3.5 How much detail?

Given the broad range of topics to be covered, there is insufficient time to deal with each one in complete detail. Instead, material is presented on a "need to know" basis. That is, only the information that the students "need to know" to make use of a given component in a design is introduced. For example, the discussion of bipolar transistors includes only the characteristic curves that describe the behavior of these devices. Students interested in the underlying physics of P-N junctions are referred to other sources. This philosophy means that students can begin to make use of these components in their designs much sooner than would otherwise be the case.

Similarly, circuit analysis is treated in a less than rigorous fashion. In our experience, the single greatest obstacle that mechanical engineering students face in R-L-C circuit analysis is the complex representation of impedance. In this course we try, where possible, to use a more intuitive approach. Consider, for example, the low pass R-C filter shown in Figure 2. Under high frequency excitation, a capacitor behaves like a short circuit and $V_{OUT} = 0$. Under low frequency excitation it behaves like an open circuit and $V_{OUT} = V_{IN}$. Hence, a low pass filter.

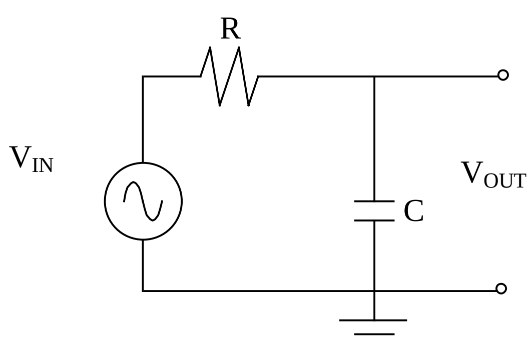

Figure 2 – a low-pass R-C filter

This simplistic approach, which works well for many of the simple circuits that are discussed in this course, dispels some of mystery of electronics which traditional electronics courses seem to instill.

The discussion of microprocessors is similar, as the principle intent is simply to get the students using a microprocessor. Toward the end of the course, some time is spent discussing microprocessor architecture, programming and I/O functions. The purpose of this discussion is to provide the necessary vocabulary to interpret microprocessor specifications. Thus, when the student finds his/herself designing a system in industry, he/she will be able to intelligently discuss the options with electrical and computer engineering colleagues.

5.0 Conclusions

Feedback from students in the 1998 offering of this course was very positive. This is reflected in the fact that the enrolment for 1999 is up by close to 50% from 1998. The popularity of mechatronics among the undergraduates bodes well for the planned development of a grouping of elective courses for students wishing to specialize in mechatronics. The current Mechatronics System Design course will be an important part of this grouping.

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